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Green Chemistry: Developments and Chemistry for Sustainable Scope

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Abstract

The green chemistry is a fast-developing technology and become a very appealing subject for academic and industrial systems. Sustainable techniques often include hazardous solvents with innocuous ones so that the latter may be included in a particular process. The green analytical chemistry is the most well-known field of study. The main topics covered in this article are the principles of green chemistry, specifics regarding safe and hazardous solvents and their reaction conditions, sustainable synthesis, catalysis, and, lastly, the industrial applications of green chemistry in the production of food, energy, water treatment, and educational materials and difficulties in the area of green chemistry. This article offers instances of green chemistry that significantly improve the sustainability of industrial processes and makes recommendations for appropriate actions that support green chemistry production in a widely accepted way.

Keywords: Synthesis, catalysis, solvents, hazardous, pollutions.

1. Introduction

The fast and sometimes rampant expansion of human endeavors has resulted in unexpected and dynamic interactions between the growing population, food consumption, industrial development, and environmental damages.[1] In particular, the environmental and health impacts of the production, distribution, use, and discharge of chemicals at larger and larger quantities in a practically closed environment have raised global concerns and resulted in the definition of sustainable development.[2-5] The green chemistry, focusing on designing chemical products and processes that minimize hazardous substances, reduces environmental pollution, conserves resources, and improves public health. It promotes safer, more efficient chemical processes aligned with sustainability principles. Most manufactured products involve one or more chemical processes.[6] We cannot imagine what our life will be like without the products produced by the chemical industry. However, on average, only a small proportion of the resources we take from the Earth is converted into the desired products in current chemical processes, and large amounts of wastes and hazardous materials are generated. How to supply humanity with enough food, energy, chemicals and materials sustainably, without damaging our planet, is an unavoidable issue.

The main goal of the chemical sector is to minimize the pessimistic effects which take place in the environmental and health sectors. To improve the life cycle of a chemical, several concepts need to get concentrated by the researchers, they are minimizing the risk and quantifying the risk occurrences in a sustainable direction.[7] As the global population is predicted to reach 9 billion by 2055, conserving food, fuel, fibers, and feed is imperative. The future lies in sustainable and renewable solutions that will help us meet these challenges.[8] The other challenges in green chemistry are multiple scientific and engineering disciplines are essential to recognize chemical and physical phenomena. Non-traditional fields like biochemistry and nano-chemistry can still benefit research. While some fields such as biochemistry and nano-chemistry are not commonly associated with traditional chemistry, they can still provide valuable insights for research in various disciplines. Since some parts of green chemistry may not be sustainable at all, a definition of sustainable chemistry should be established and applied for the assessment of each chemical or reaction or process.[9] In general, sustainable chemistry should use resources, including energy, at a rate at which they can be replaced naturally, and the generation of waste cannot be faster than the rate of their remediation. It should be noted that not all sustainable chemicals or reactions or processes could be green. Therefore, the selection of chemicals, reactions, and processes, which are sustainable and green at the same time, should be preferred or the target of design and innovation.[10]

2. Principles of green chemistry

1. **Prevention:** It is better to prevent waste than to treat or clean up waste after it is formed.
2. **Atom economy:** Synthetic method should be designed to maximized the incorporation of all materials used into the final product.
3. **Less hazardous chemical syntheses:** Wherever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
4. **Designing safer chemicals:** Chemical products should be designed to preserve efficacy of function while reducing toxicity.
5. **Safer solvents and auxiliaries:** The use of auxiliary substances (e.g. solvents, separation agents, etc.) should be made unnecessary wherever possible and, innocuous when used.
6. **Energy efficiency:** Energy requirements should be recognized for their environmental and economic impacts and should be minimized. Synthetic methods should be conducted at ambient temperature and pressure.
7. **Renewable feedstocks:** A raw material of feedstock should be renewable rather than depleting wherever technically and economically practicable.
8. **Reduce derivatives:** Unnecessary derivatization (blocking group, protection/deprotection, temporary modification of physical or chemical processes) should be avoided whenever possible.
9. **Catalysis:** Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

10. **Design for degradation:** Chemical products should be designed so that at the end of their function they do not persist in the environment and break down into innocuous degradation products.
11. **Real-time analysis for pollution prevention:** Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
12. **Inherently safer chemistry:** Substances and the form of a substance used in a chemical process should be chosen so as to minimize the potential for chemical accidents, including releases, explosions, and fires. Green chemistry is a tool in achieving sustainability it's not a solution to all environmental problems but Fundamental approach to pollution prevention and chemistry's unique contribution to sustainability

3. Efficient synthetic routes

Most current chemical production processes lack efficiency in using feedstocks and produce a large amount of wastes. Increasing atom economy is crucial for reducing both the depletion of raw materials and the generation of waste.[11] Ideally, all the atoms in reactants should be transformed into the desired products. However, the achievement of 100% atom economy in all industrial chemical processes is not realistic. Another way to eliminate waste is integration of different reactions and processes, in which the by-product in one reaction is the feedstock of another. Exploration of atom economic synthetic protocols and routes to increase the synthetic efficiency and reduce or eliminate wastes is a long-term task.

4. Greener and functional solvents

Huge amounts of toxic, flammable and volatile organic solvents are used in chemical processes to prepare chemicals and materials. About 20 million tons of organic solvents are released to the atmosphere each year, leading to solvent waste and environmental pollution.[12] The use of greener solvents such as water, supercritical fluids, ionic liquids, non-toxic liquid polymers and their various combinations in chemical processes has become a major focus of research in academia and industry. A green solvent should meet some basic requirements such as low toxicity, ease of availability and recycling, and high process efficiency. It is known that the efficiency of a process usually depends strongly on the properties of the solvents used. Because of their special properties and functions, green solvents can be used to optimize chemical processes, decrease solvent usage and processing steps, and develop new routes and technologies that meet the requirements of sustainability.

5. Greener catalysis

Catalysis plays a key role in the chemical industry because most chemical processes need catalysts to accelerate reactions, enhance selectivity and lower energy requirements.[13] Current catalysts are often based on expensive, toxic, harmful or noble metals. Green catalysts should have some common characteristics such as high activity, selectivity, and stability, and ease of separation and reuse; they should be based on environmentally benign and widely available raw materials such as abundant metals, organic compounds and enzymes. The exploration and development of new synthetic routes and chemical processes rely strongly on progress in catalysis. The design and use of green catalysts and catalytic systems to achieve the dual goals of environmental protection and economic benefits is an important task, and is essential for the sustainability of the chemical industry.

6. Use of green and renewable feedstocks

Currently, our energy supply and the feedstocks for producing organic chemicals and materials are mainly based on fossil resources, which are not renewable and are diminishing. The use of renewable carbon resources, i.e. biomass and CO_2, in the chemical and energy industries is extremely important, and different routes and processes have been developed.[14] However, we face thermodynamic, kinetic and technical challenges in the conversion of biomass and CO_2 into fuels and chemicals. Many current routes are technically feasible, but economically prohibitive, and only very small proportions of the resources are currently used. The development of efficient methods for converting biomass and CO_2 into useful chemicals and liquid fuels through energetically and economically viable industrial processes is of great importance, but is challenging. Moreover, the use of greener, cheaper, safer reactants and sustainable energy sources, such as oxygen, hydrogen peroxide and solar energy, in chemical processes is also an interesting area.[15]

7. Green engineering and products

It should be emphasized that green chemistry covers engineering aspects and green products.[16] Chemicals and materials are produced by industrial chemical processes, and therefore, clean, energy-efficient and mass-efficient processes and technologies are essential tools for achieving the goal of maximizing efficiency and minimizing wastes. Many current pharmaceuticals, fine chemicals, commodity chemicals and polymers are harmful. Products that are benign to human health and the environment need be designed and produced to replace hazardous products. Clearly, the exploration of synthetic routes, design of sustainable products and solvents, and exploration of new catalysts and chemical processes are closely related, and should be integrated. In addition, economic benefits are the central driver for the development of green chemistry and technology.

8. Future works

Green chemistry will be one of the most important fields in the future. Although this field has developed rapidly in the last 20 years, it is still at an early stage. Promoting green chemistry is a long-term task, and many challenging scientific and technological issues need to be resolved; these are related to chemistry, material science, engineering, environmental science, physics and biology. Scientists, engineers and industrialists should work together to promote the development of this field. There is no doubt that the development and implementation of green chemistry will contribute greatly to the sustainable development of our society.

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